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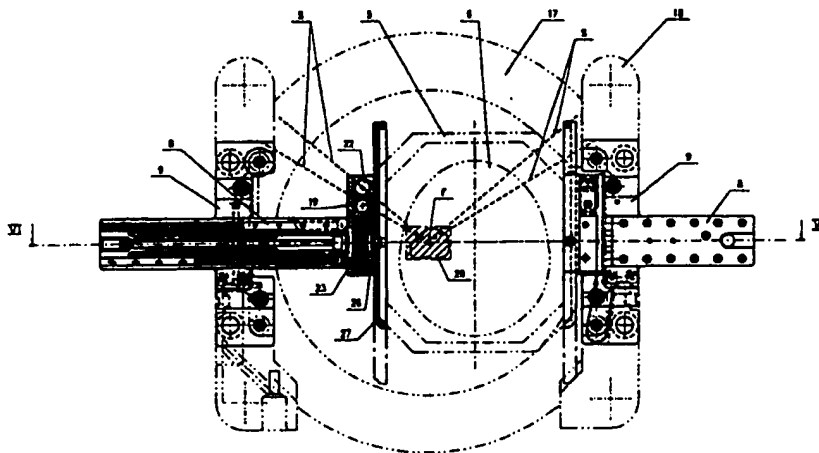
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(54) Title: POSITIONING DEVICE AND METHOD FOR RADIATION TREATMENT



## (57) Abstract

A radiotherapy appliance having controllable radiation beam(s) which converge on a focus volume wherein an object being irradiated can be movably positioned relative to the focus volume for varying time periods and with varying radiation exposure rates, optimally under control of a computer. The computer controls the focus volume radiation beam size, intensity and exposure time for subareas of the treatment target in response to a radiation dose distribution determined for the treatment target. A determination of the radiation beam size, intensity and dwell time of the focus volume in the target area, is made by initially dividing up the specified treatment area into volume elements or voxels and having biological characteristics of the treatment area assigned to each voxel. The energy deposition incident to each voxel to provide this biological characteristic is then calculated. Finally, from the energy deposition incident on each voxel, the dwell time of the focus volume at particular voxels can be determined. Once the dwell time has been determined, the computer generates a sequence of motor control movements to move the patient with respect to the focus volume such that the focus volume is at a position sufficiently long within the treatment target to deliver the necessary radiation for each voxel.

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## POSITIONING DEVICE AND METHOD FOR RADIATION TREATMENT

Field of the Invention:

This invention relates to a method and device for treating a patient with ionizing radiation. In the practice of the invention, a patient is moved relative to an ionizing radiation source during treatment. By moving the patient during treatment, it is possible both to minimize radiation delivered to areas outside a target volume and to take into consideration, in treatment planning, the biological properties of different areas inside and outside the target volume.

Background of the Invention:

It is known that exposure of tissue to ionizing radiation will kill the cells exposed. In the process of conventional radiation therapy, however, significant volumes of normal tissue in addition to pathological tissue, are exposed to harmful levels of radiation.

Several methods have been employed in the prior art to minimize the exposure of healthy tissue to ionizing radiation. For example, devices which direct radiation at the tumor from a number of directions have been used. In such devices, the amount of ionizing radiation emanating from each source of radiation is less than that which is necessary to destroy tissue. Rather, tissue destruction occurs where the radiation beams from multiple sources converge, causing the radiation level to reach tissue-destructive levels. The point of convergence of the center of multiple radiation beams is referred to herein as the "focus point". The radiation field surrounding a focus point is herein referred to as the "focus volume." The size of the focus volume can be varied by varying the size of the intersecting beams.

One such radiation appliance sold under the name GAMMA KNIFE (Elekta Instruments S.A.) comprises an ionizing radiation shield having a substantial number of ionizing radiation sources. Radiation passes through a number of channels all of which lead toward a common focus

point in a recess within the radiation shield. Such a system is referred to, and described in, US patent 4 780 898. Another system commonly termed a LINAC (or linear acceleration) involves an ionizing radiation source which moves circumferentially around a focus point delivering a series of beams of ionizing radiation through the focus volume. A patient's head, immobilized in a stereotactic instrument which defines the location of the treatment target in the patient's head, is secured by a system which positions the treatment target in coincidence with the above-mentioned focus point.

The ionizing radiation in the focus volume of these radiation appliances is intense compared to the radiation emanating from each individual beam of the device. Areas outside of the focus volume receive less substantial amounts of ionizing radiation. Therefore, pathological tissue can be treated while avoiding surrounding healthy areas.

In general, the focus volume is spherical because the intersection of multiple radiation beam cross sections approximately form a sphere of constant radiation density at each point equidistant from the focus point. As a result, when the shape of the pathological tissue volume is not substantially spherical, either some areas of pathological tissue do not receive enough radiation or other areas of healthy tissue receive too much radiation. In other words, variations in radiation sensitivity within the focus volume cannot be taken into account. To ensure that the whole volume of pathological tissue is fully exposed to the radiation field, the radiation team is obliged to deliver damaging doses of radiation to healthy tissue within the focus volume.

It is possible to reduce the volume of healthy tissue receiving high ionizing radiation doses by reducing the size of the focus volume and manually repositioning the patient a number of times such that the different positions of the various focus volumes would effectively

cover the entire pathological tissue volume. While this method allows increased conformity between pathological tissue volumen and shape and the volume receiving high radiation doses, the time required to manually reposition a patient a sufficient number of times for the selected focus volume size to effectively cover the pathological tissue can require unreasonably long treatment periods. Moreover, each manual reposition introduces the potential for mistakes with resultant increased radiation of helthy tissue.

A second potential means for minimizing the irradiation of healthy tissue would be to vary individual beam size and intensities whereby the shape of the focus volume could be modified to conform more accurately with the pathological tissue volume. With the many possible combinations of incident beam sizes and intensities to be interactively evaluated by the radiology team in order to find a radiation dose distribution appropriate for treating a pathological tissue volume having a specific shape, the experience of the radiotherapy team in choosing the beam sizes and intensities becomes a significant factor in the efficiency and effectiveness of the radiation treatment.

A further solution involves the projection of a focus volume of ionizing radiation onto a treatment area. Such a technique is described in, for example, Experimental Verification of an Algorithm, for Inverse Radiation Therapy Planning, Radiotherapy and Oncology, 17 (1990) 359-368. According to this article, it is impractical to move the patient with respect to a fixed focus point. This conclusion was based on Therapy Planning and Dosimetry for the Pion Application at the Swiss Institute for Nuclear Research, Radiation and Environmental Biophysics, 16, 205-209 (1979), which was reported to have demonstrated that dynamic movement of the patient in a pion generaton was not feasible.

Thus, although the prior art suggests radiation treatment of an object in which the dose distribution closely conforms to the treatment area within the object, the methods are dependent on the skill and experience of the radiology team, involve potential errors during manual repositioning and/or require prolonged treatment times. In contrast to these prior art methods, the present invention - by means of automatic positioning and repositioning of a target area relative to a focus volume - eliminates the risks of manual error, allows use of smaller focus volumes, thereby improving conformity between a radiation field and a target volume and reducing the need for trial and error approach associated with multiple size focus volumes, and shortens the treatment planning time. In addition, contrary to the teaching of the prior art, the present invention permits dynamic movement of an object relative to a radiation source, whereby greater local conformity of dose delivery to pathological tissue volume and shape becomes possible by movement at rates which modulate radiation deposition based on the tissue cellular properties such as radiation sensitivity both inside and outside of the target volume.

Summary of the Invention:

The present invention provides a medical radiation treatment method and apparatus having a focus volume, the position of which remains fixed with respect to the ionizing radiation source but is variable with respect to the object to be radiated. In the practice of the invention, an object is moved with respect to the focus volume of an ionizing radiation source whereby a plurality of subareas within the object are subjected to varying radiation intensity levels for varying dwell times. The dynamic movement is guided by a computer controlled positioning device to provide a radiation dose distribution. The radiation dose distribution closely conforms to a desired radiation dose distribution taking into account both the biological response of the various

tissues being subjected to radiation and the shape of the target volume. The focus volume size and shape may be varied in cooperation with the movement of the object to further optimize the radiation treatment.

5       A determination of the focus volume size, intensity, and dwell time of the focus volume in the target area, is made by initially dividing up the specified treatment volume into volume elements or voxels. Biological characteristics of the treatment volume are then assigned  
10 to each voxel. A probability for achieving complication free control of pathological tissue is then calculated for each voxel based on the biological characteristics. The energy deposition incident to each voxel which is needed to provide this probability of complication free tumor  
15 control is thereupon calculated. Finally, from the energy deposition incident on each voxel, the dwell time of the focus volume at particular voxels is determined. Once the dwell time has been determined, it is possible to determine the order of movements necessary to position the  
20 object with respect to the focus volume to deliver the necessary radiation for each voxel.

A device which allows a patient to be dynamically positioned with respect to the focus point is used to practice the method of this invention. In this device, a  
25 computer is used to generate a number and order of motor control movements which cause the target volume to be moved and positioned with respect to the focus point for the requisite time. In a preferred embodiment, a positioning device is attached to a suspension arrangement  
30 which is secured to a radiation appliance and is translatable in the X, Y and Z directions via two electronically controlled motor assemblies.

Brief Description of the Drawings:

Fig. 1 illustrates a radiation treatment system  
35 according to the present invention.

Fig. 2 illustrates a flow chart for a computer program for use in a radiation treatment system according to the present invention.

Fig. 3 illustrates a modulator suitable for use in a radiation treatment appliance according to the present invention.

Fig. 4 illustrates an alternate form of modulator suitable for use in a radiation treatment appliance according to the present invention.

Fig. 5 illustrates a suspension system for moving a positioning device with respect to a radiation source according to the present invention.

Fig. 6 depicts the embodiment of Fig. 5 along section VI-VI.

Detailed Description of the Invention:

Fig. 1 illustrates a radiation treatment system useful for carrying out the radiation treatment method according to the present invention. In particular, Fig. 1 illustrates the coordination of various parts of a radiation treatment appliance 103, having an electronically controlled positioning device 105 and an ionizing radiation unit 110, to deliver controlled radiation to selected parts of an object under treatment. The use of an electronically controlled positioning device in combination with calculated radiation doses for individual voxels based on biological radiation response characteristics enables the radiation system illustrated in Fig. 1 to dynamically control the radiation treatment of the target by moving the target with respect to the focus point. Specifically, the radiation treatment system of Fig. 1 optimizes the radiation delivery of individual voxels on a real time basis so that radiation absorbed in the target conforms to the desired radiation doses associated with desired biological responses of the various tissues to be treated.



Input data system 150, illustrated in Fig. 1, comprises a system for generating and/or storing three dimensional geometric coordinates of the treatment volume within an object such as a patient. This system also  
5 generates and/or stores the types of biological responses of the target volume and surrounding tissues to be treated. The input data system 150 transmits the treatment volume data to the host computer system 100. The input data system 150 is, for example, a conventional computer  
10 graphics system which stores three dimensional coordinates of a treatment volume and associated subvolumes of the treatment volume with data representing biological properties of the subvolumes. The host computer 100 converts this data into a series of motor control,  
15 radiation beam size, and radiation beam energy output control signals through a computer program such as illustrated in Fig. 2. The host computer sends radiation control signals to the radiation modulators 45 of the radiation unit 110 device over wire 130 to control the  
20 size and/or intensity of the radiation beams emanating from the radiation source to irradiate the treatment volume.

The radiation unit 110 includes an radiation source which projects one, two or more beams of radiation and a  
25 means to control radiation beam size, such as modulators 45. The radiation source of the radiation treatment appliance may be any of variety of conventional ionizing radiation sources which produce an effective focus volume of radiation. A focus volume is typically formed by the  
30 intersection of plurality (two to several hundred) of radiation beams emanating from the radiation source. The beam axes are directed at a fixed point with respect to the radiation source. The focus volume is the summation (over the volume of the intersecting radiation beams) of  
35 radiation densities from each of the intersecting radiation beams. An effective focus volume can also be formed by directing the axis of a single radiation beam

through a fixed point from a plurality (typically 2 to 360) of different angles. Such a technique is commonly used in linear accelerator type radiation units.

The host computer 100 also sends the motor control  
5 signals through wires 120 to each of a first, a second and a third motor assemblies, each having motors 21, 22 and 25, within the electronically controlled positioning device 105. The first and second motor assemblies cooperate so that motors 21, 22 and 25 in the first  
10 assembly always move precisely the same distance as motors 21, 22 and 25 in the second assembly. The first and second motor assemblies are each connected to feedback system 170 which compares the translation distance of motors 21, 22 and 25 in the first motor assembly with the translation  
15 distances of motors 21, 22 and 25 respectively of the second motor assembly. When a pair of cooperating motors 21, 22 or 25 do not have approximately (i.e. > 0.2 mm difference) the same translation distance, an error detection feedback system 170 generates a feedback error  
20 signal to terminate all motor movement and radiation exposure which is sent through wire 180 to the host computer system 100. When the computer system has terminated motor movement and radiation exposure due to this feedback signal, the motors can then be recalibrated,  
25 and treatment restarted. Feedback system 170 also monitors the radiation intensity by monitoring the beam sizes produced by the radiation modulators which form the focus volume. The beam size is controlled by the host computer 100 through radiation modulators 45 for each beam. When a  
30 modulator forms a beam having a cross section larger or smaller than desired, then the error detection feedback system 170 transmits an error signal to the host computer which, in turn, generates control signals to the cooperating motors which move the patient away from the  
35 focus volume of the radiation treatment appliance. Alternatively, when the error detection feedback system 170 senses that the radiation beam size is not correct,

then feedback system 170 transmits an error signal to the host computer 100 which then turns off the radiation source.

Manual controller 160 consists of a joystick  
5 mechanism or the like which generates signals for manually controlling cooperating motors 21, 22 and 25. These signals are transmitted to both sets of cooperating motors 21, 22 and 25 over wire 120 through host computer system 100. Monitor 165 displays an image corresponding to a focus  
10 point and a treatment volume as the treatment volume is moved with respect to the focus point in response to the signals sent to cooperating motors 21, 22 and 25.

Fig. 2 illustrates a computer program 200 used by a computer 100 of the radiation treatment system according  
15 to the present invention for controlling radiation deposition within the treatment volume of an object by automatically moving the object with respect to the focus volume. The computer program generates signals to control motors which move the object so as to have a radiation  
20 focus volume dwell in a location for a sufficient time to deliver the appropriate radiation intensity for that location. Initially, the three dimensional coordinates of the treatment volume and the biological characteristics of the tissue in the treatment (and surrounding) volume are  
25 generated and sent 203 to the computer system. The treatment volume is then segmented 205 into volume elements or voxels having a minimum volume smaller than the focus volume which is generated at the intersection of the radiation beams. Biological responses to radiation of  
30 tissue associated with the treatment area are then assigned 220 to the voxels. The specification of tissue types allows the treating physician to treat, through computer controlled radiation, different types of tumorous regions which may react differently to specific radiation  
35 doses.

Once the tissue types for each voxel have been established, the computer program 200 selects a desired biological response 230 for each voxel which depends on a radiation dose for that voxel. This selection generates a  
5 desired radiation dose distribution  $\Phi(r)$  for the treatment volume. A specific example of such a biological response is the maximum probability of complication free control of pathological tissue (P+) chosen for each voxel. P+ is the probability of achieving control for a specific type of  
10 tissue for a specified radiation dose minus the probability of fatal complications for that radiation dose and tissue type. The data relating to the probability of control is provided to the computer program from ongoing or previously published clinical studies. Selecting a  
15 maximum P+ for each voxel generates an optimum radiation distribution for pathological tissue control because each selected P+ has an associated radiation dose. The generation of P+ can alternately be defined as the probability of control for a specific type of tissue for a  
20 specified radiation dose minus the probability of adverse (not necessarily fatal) complications from that radiation dose for that type of tissue. Alternatively, biological responses of tissue to radiation may be selected depending on the location of the treatment volume relative to other  
25 treatment volumes. Further, other biological responses of tissue to radiation may be chosen which would generate different radiation dose distributions for the tissue. These selections of biological response provide a treating physician more degrees of freedom in treatment doses for  
30 different types and locations of tissues.

Once a desired radiation dose  $\Phi(r)$  for each voxel has been generated in step 230, the computer program 200 must specify how any particular voxel will receive the required dose. This is a problem because radiation beams focused on  
35 any one voxel will contribute radiation exposure to adjacent voxels. The computer program 200 solves this problem by first determining 240 an energy deposition

kernel  $H(r, r')$  which is the mean specific energy imparted to a point  $r$  per unit energy incident on a volume centered at  $r'$ . The program 200 assumes that  $H(r, r')$  is spatially independent. That is, the energy imparted at point  $r$  from a focus volume centered at  $r'$  is only a function of the distance between  $r$  and  $r'$ . A consequence of this assumption is that the calculated dose distribution  $D(r)$  can be expressed as the integral of the density  $F(r')$  of energy deposition kernels  $H(r, r')$  over the same volume.

10 The integral expression is then solved via conventional analytical or iterative techniques for one of  $D(r)$  or  $F(r')$  given  $H(r, r')$  and either  $F(r')$  or  $D(r)$  respectively. The energy deposition kernels  $H(r, r')$  are known and are inputs for the integral expression because the energy

15 distribution associated with the physical intersection of multiple radiation beams of a given cross section for any one focus volume is known. The kernel may be simulated, for example, by rotating a normalized beam cross section through 360 degrees. Energy deposition kernels  $H$  are

20 assigned to each voxel in step 240.

Once the energy deposition kernels for all voxels have been determined, the calculated radiation dose distribution  $D(r)$  is determined by iteratively solving for the radiation density  $F(r')$ . That is, an initial density

25  $F_0(r')$  for each voxel is assumed, multiplied by the deposition kernel for each voxel, and then summed over the total treatment volume. The initial calculated dose distribution  $D_0(r)$  is then compared 250 to the desired radiation dose  $\Phi(r)$  and an error term is generated. The

30 assumed initial density is adjusted  $F_1(r')$  as a function of the error term and the next  $D_1(r)$  is calculated. This iteration procedure continues until the calculated  $D_n(r)$  after  $n$  iterations is sufficiently close to the desired  $\Phi(r)$ . The initial assumed density is chosen to deliver a

35 substantial overdose to the treatment area. The error term represents a decrease in beam density. As a result, the convergence of the iterative calculations will guarantee

that the treatment area will not receive less than the desired dose. This consideration assures that there will not be an underexposure of a treatment area. The result of iteration step 250 is a density  $F(r)$  for each voxel which  
5 specifies the time duration that a specific kernel should dwell on any one voxel. Typically, the iteration converges at approximately  $n=200$  or before.

Once the duration of a specific kernel on any particular voxel is known, the computer 100 generates  
10 (270) control signals which are sent to the modulators 45 and to both sets of cooperating motors 21, 22 and 25. The control signals sent to the modulators 45 adjust the radiation beam size, and hence the kernel size for any selected voxel. The control signals sent to the  
15 cooperation motors, 21, 22 and 25 move the patient with respect to the focus volume such that the radiation energy incident on the focus volume has a duration on any particular voxel only long enough to deliver the required beam density to that particular voxel. The movement of the  
20 target volume relative to the focus volume may be continuous while the target volume is exposed to radiation and the speed may be slowed or accelerated to result in an appropriate dwell time. Alternatively, movement may comprise sequential movement or re-positioning of the  
25 target volume in a multiplicity of positions relative to the focus volume. In this case, the radiation source is pulsed off while the target volume is moved and pulsed on while the target volume is stationary. As used herein, the term "sequential movement" means that stopping the  
30 movement of the target volume, irradiation the target, volume, and moving the target volume again. In a preferred embodiment, the focus point is not moved outside of the object containing the target volume while this sequential re-positioning is occurring.

35 Cooperating motors 21, 22 and 25 as well as modulators 45 will continue to control the radiation deposited in the patient until the feedback system 170 of

the radiation treatment system detects that either the opposing motors are not moving synchronously or that one or more of the radiation sources are not producing the required beam intensity or that the modulators 45 are not  
5 producing the required beam shape. When either of these conditions occur, the computer program will generate 280 commands to stop motor movement and/or stop radiation exposure. At this point, the program 200 will prompt the user 285 for an evaluation of whether to proceed with the  
10 remaining computer controlled treatment or proceed with manual operation. When the user wants to return to computer control, a new sequence of control movements are generated 270 taking into account that part of the previous treatment already accomplished. When the user  
15 requests manual operation, the program releases control over the radiation treatment system and transmits signals from the manual controller 160 to both sets of cooperating motors 21, 22 and 25.

The apparatus described above may be adapted to any  
20 radiation unit 110 which delivers ionizing radiation to a focus volume, such as a Gamma Knife<sup>TM</sup> or LINAC radiation treatment system, or a heavy particle beam system. In order to control radiation delivery, the channel(s) through which radiation is delivered may be provided with  
25 radiation modulators 45 such as shown, in Fig. 3. The radiation modulators 45 may be configured as opposingly faced lead plates or wedges of the like which are moveable relative to each other to form a variable slit of opening for modulating the shape or intensity of the radiation  
30 beam passing through the opening.

Fig. 3 illustrates a top view of modulator 45. In particular, moveable lead plate 60 is disposed over moveable lead plate 70. Plate 60 has a diamond shaped opening 62 therethrough and plate 70 has a diamond shaped  
35 opening 72 therethrough. Openings 62 and 72 converge to form opening 65 through both plates 60 and 70. The relative position of plates 60 and 70 determine the size

of opening 65 through which a radiation beam passes. The size of opening 65 shapes the radiation beam passing through opening 65.

Fig. 4 illustrates an alternate form of modulator suitable for incorporation in the present invention. The modulator illustrated in Fig. 4 is formed from two sets 80 and 82 of opposingly oriented slats of radiation blocking material. The slats may also be formed of radiation modulating material which transmits selective intensities of radiation depending on the energy of the incident radiation. Individual slats within a first or second set form a planar surface substantially perpendicular to the direction of the radiation beam. The two sets of slats are oriented with respect to each other such that they form the radiation beam cross section. The slats are moveable with respect to each other, and as they are moved, the beam cross section is modulated. For example, slat 80(a) moves relative to slat 82(a) to form part of opening 85 and slat 80(b) moves relative to slat 82(b) to form another part of opening 85. Any other suitably shaped and sized modulator may be used in the practice of the invention.

The radiation sources within the radiation unit 110 are preferably ionizing radiation sources which emit high energy (gamma or x-ray) photons or heavy charged particles.

As illustrated in Fig. 5 and 6 an object such as a patient's skull 6 is immobilized with respect to a fixation device 5 within an electronically controlled positioning device 105. The electronically controlled positioning device 105 includes a base 17, a suspension system, and a fixation device 5. The fixation device 5 is moveable with respect to the radiation device. During treatment, the fram 5 is moved by the positioning device to the positions necessary to allow the focus point F of the radiation beams to be located within the target volume 28. The focus point is at the intersection of the



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plurality of radiation beams S. The positioning device is secured to the radiation appliance by a base 17. The suspension system, attached to the base 17 by bracket 18, translates the fixation device 5 in the horizontal and vertical planes, i.e. the 3 dimensional coordinate system, with respect to the radiation source and the focus point F. This suspension arrangement comprises a pair of horizontal beams 8 or the like which are oriented in line with each other, translatable in their lengthwise direction, and slidably supported in associated guides 9 of bracket 18.

The outer end of each beam 8 is connected to the associated part of the bracket through a screw jack means 19 which via gear assembly 20 is linked to an electronically controlled motor 21 within the beam 8. The motor 21 is in a parallel orientation to the screw components of the screw jack means 19, as shown in Fig. 6. The motor 21 is preferably operated via NC control from the computer or the like (not illustrated) following a dedicated computer program. Both motors 21 function cooperatively and form a motor assembly arranged to translate the stereotactic instrument 5 in the X direction.

Additionally, adjacent the inner end of each beam 8, an electronically controlled motor 22 is connected to, and supported by, a beam 23 which encloses a screw jack means 24 also connected to the motor 22. The beams 23 are parallel and disposed opposite each other. The motors 22 are also electronically controlled, operated via NC control from the computer and cooperate to form a motor assembly arranged to translate the stereotactic instrument in the Z direction.

A further electronic motor 25 is connected to, and supported by, a beam 26 adjacent the inner end of each beam 8, beyond the respective beam 23. The beams 26 are mutually parallel and disposed opposite each other. Each beam 26 is attached to the static portion of a respective

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screw jack means 24 and guided with guides (not shown).  
The screw jack means (not shown) are further connected to  
the respective motor 25. The motors 25 are also  
electronically controlled, operated via NC control from  
5 said computer or the like and cooperative to form a motor  
assembly which is arranged to translate the stereotactic  
instrument 5 in the Y direction. The screw jack means (not  
shown) supports an attachment means 27 to releasably  
secure the stereotactic instrument in a defined position  
10 in the suspension arrangement.

A fixation device 5 suitable for use in this  
invention when immobilizing a patient's skull in the  
positioning device is, for example, a stereotactic frame.  
The frame is fixed to the skull of the patient and mounted  
15 to the suspension system. The frame may be fixed to the  
skull of the patient by means of surgical twist drills  
passing through skin and looking into underlying bone.  
Alternatively, the fixation device 5 may be one which is  
non-invasive and/or allows the frame to be relocatably  
20 positioned on the patient.

The pair of cooperating motors 21 are opposingly  
disposed and operate in synchronization. In particular,  
when the motors do not move the stereotactic frame  
concurrently the same distance, then the error detection  
25 feedback system 170 (not shown) connected to the pair of  
cooperating motors 21 signals the computer that the  
orientation of the stereotactic frame is not correct and  
the program moving the stereotactic frame is stopped so  
that the stereotactic frame can be reoriented.

30 A personalized computer program for a patient's  
treatment controls the movements of each motor assembly  
21,21; 22,22 and 25,25. In this way, the stereotactic  
instrument 5 and therefore the patient's skull 6 is moved  
in the X, Y and Z directions within the helmet 17 and  
35 different parts of the treatment target 28 are  
successively positioned at the focus point F for various  
time periods in accordance with said program. The

movements of both of the motors in each motor assembly are continuously checked against each other by the computer and if the movement of one motor differs from the respective cooperation motor, the computer issues a stop  
5 signal and treatment is suspended. Computer operation gives enhanced reliability and even the possibility, if so desired, to break off treatment and to afterwards resume treatment at the appropriate point in the computer program.

10 While this invention has been particularly described and illustrated with reference to particular embodiments thereof, it will be understood by those of skill in the art that changes in the above description or illustrations may be made with respect to form or detail without  
15 departing from the spirit or scope of the invention. In particular, any controlled movement means which allows the object being irradiated to be moved relative to a radiation source may be employed.

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CLAIMS

1. A method of selectively irradiating an object, comprising determining the position of a focus point with respect to a radiation unit; immobilizing an object with respect to a fixation device; coupling said fixation device to a suspension system; fixing a position of said fixation device by said suspension system with respect to said radiation unit to determine the position of said object; and moving said fixation device by said suspension system with respect to said focus point to expose said object to radiation from said radiation unit.

2. A method of selectively irradiating an object, as in claim 1, further comprising exposing said object to radiation while moving said object.

3. The method of selectively irradiating an object, as in claim 1 or 2, further comprising modulating a radiation beam of said radiation unit to modulate a focus volume of said radiation unit.

4. The method of selectively irradiating an object, as in claim 1 or 2, further comprising modulating a radiation source of said radiation unit to modulate a focus volume of said radiation unit.

5. A method of selectively irradiating an object, as in claim 1 or 2, wherein said object maintains a position with respect to said focus point during said movement such that said focus point remains inside said object while said object is being moved.

6. The method of selectively irradiating an object, as in claim 1 or 2, further comprising subdividing a treatment area of said object into a plurality of voxels; selecting a biological response to radiation for a plurality of said voxels; determining a radiation dose corresponding to each of said voxels to produce said biological response; and maintaining said object at a location with respect to said focus point for a time sufficient to deposit said radiation dose corresponding to each of said voxels into each of said voxels.

7. A method of selectively irradiating an object, as in claim 6, wherein said radiation dose corresponding to each of said voxels is determined with respect to radiation doses corresponding to adjacent voxels.

5        8. A method of selectively irradiating an object, as in claim 2, wherein said object maintains a position with respect to said focus point during said movement such that said focus point remains inside said object while said object is being moved.

10       9. A radiation appliance, comprising a radiation unit for irradiating an object with a focus volume and a fixation device coupled to said radiation unit by a suspension system, wherein said fixation device immobilizes an object to be irradiated by said radiation  
15 unit, and said suspension system moves said fixation device to expose and/or while exposing said object to radiation.

20       10. A radiation appliance, as in claim 9, further comprising a computer coupled to said suspension system for controlling said suspension system said suspension system responds to signals transmitted from said computer by moving said fixation device to expose and/or while exposing said object to radiation from said radiation unit.

25       11. A radiation appliance, as in claim 10, wherein said computer is coupled to said radiation unit and said computer transmits signals to said radiation unit to modulate at least one radiation beam emitted from said radiation unit.

30       12. A radiation appliance, as in claim 10, wherein said computer is coupled to said radiation unit and said computer transmits signals to said radiation unit to modulate a radiation source of said radiation unit.

35       13. A radiation appliance, as in claim 11, further comprising an error detector coupled to said radiation unit, said suspension system and said computer; said error detector detects when said suspension system does not move

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said fixation device as indicated by said signals received  
by said suspension system from said computer; said error  
detector detects when said radiation unit beam is not  
modulated as indicated by said signals sent from said  
5 computer; and said error detector transmits an error  
signal to said computer when said error detector detects  
an error.

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## AMENDED CLAIMS

[received by the International Bureau on 31 October 1995 (31.10.95);  
original claims 1-13 replaced by amended claims 1-6 (2 pages)]

1. A device to position a patient's skull (6) within a radiosurgical appliance, such as the Gamma Knife™ which  
5 comprises a radiation shield (2) having a substantial number of radiation sources and corresponding channels directed towards a common focus point (F) in a recess within the radiation shield;  
the positioning device comprising a helmet (17) having  
10 channels extending therethrough corresponding in number and orientation to the channels in the radiation shield, a couch assembly (14) which is moveable along a stationary base (13) secured adjacent the radiosurgical appliance, a bracket device (18) on the couch assembly to firmly secure  
15 the helmet thereby allowing it to be introduced into the recess in the radiation shield, and a stereotactic instrument (5) in which the patient's skull is immobilized in order to locate a treatment target (28) in the skull, wherein the stereotactic instrument (5) is adapted to be  
20 secured relative to the helmet so that the target can be brought into coincidence with said focus point;  
characterized in that the stereotactic instrument (5) is clamped in a suspension arrangement (8, 19-27) which is secured to the bracket device (18) and is translatable in  
25 the X, Y and Z directions via three electronically controlled motor assemblies (21,21; 22,22; 25,25) operated by a computer or the like, such that different parts of the treatment target (28) can be successively or continuously positioned in the focus point (F) for  
30 individual time periods and with individual rates, under control of said computer.
2. A device according to claim 1, characterized in that each motor assembly (21,21; 22,22; 25,25) comprises a  
35 pair of cooperating motors whereby the first motor (21,22,25) in each assembly is disposed on a first side of the stereotactic instrument (5) and the second motor

(21,22,25) is disposed on the opposite side of the stereotactic instrument (5).

3. A device according to claim 2, characterized in that  
5 the motors (21,21; 22,22; 25,25) are controlled via NC control whereby the movements of the motors in each motor assembly are checked against each other and a stop signal is issued by said computer if the movement of one motor differs from that of the respective cooperating motor.
- 10 4. A device according to any preceding claim, characterized in that the suspension arrangement (8,19-27) is connected to the bracket device (18) via a pair of horizontal, or alternatively vertical, beams (8) which are  
15 in line with each other and translatable in their longitudinal direction, the respective outer ends (15) of which are propelled by respective motors (21,22,25) in the associated motor assembly (21,21; 22,22; 25,25) and the respective inner ends of which support a motor associated  
20 with one of the other motor assemblies.
5. A device according to claim 4, characterized in that the outer end (15) of each beam (8) is connected to the associated portion of the bracket device (18) via a motor  
25 driven screw jack means (19), and in that each beam (8) is slidably supported in a respective guide (9) in the bracket device (18).
6. A device according to claim 4 or 5, characterized in  
30 that the motors (21,21) belonging to the beams (8) are arranged to be driveable in opposite directions in order to propel the beams toward or away from each other so as to respectively release or secure the stereotactic instrument (5) in the suspension arrangement (8, 19-27).

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FIG. 1

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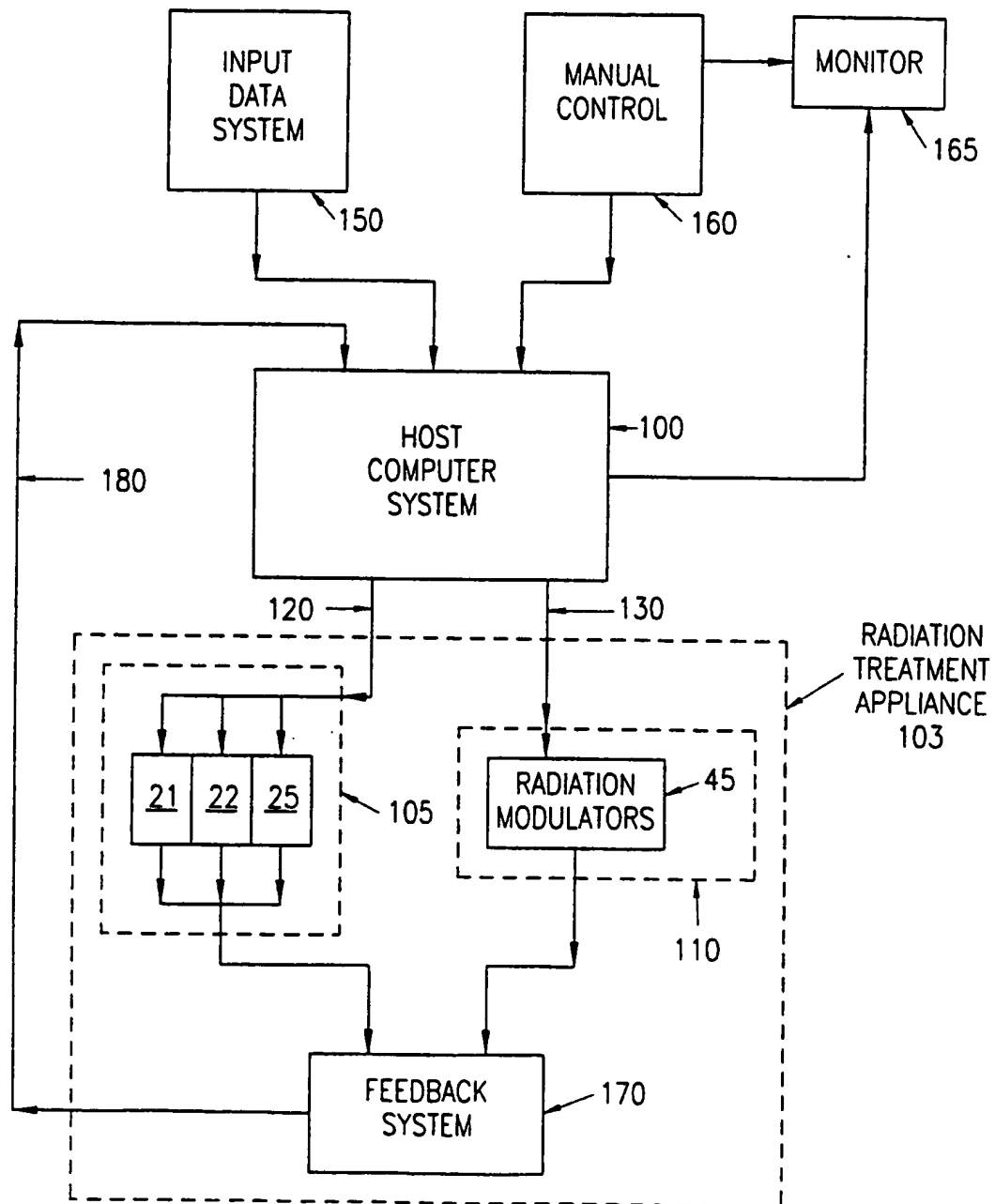


FIG. 2

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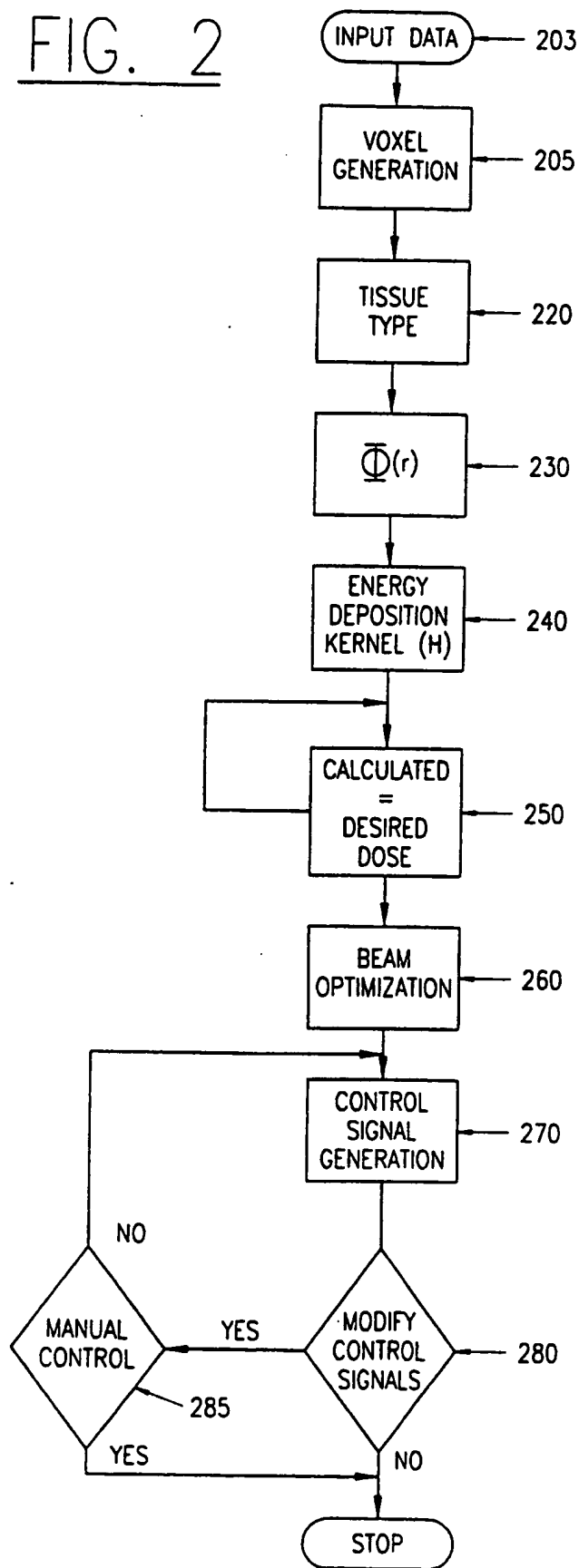
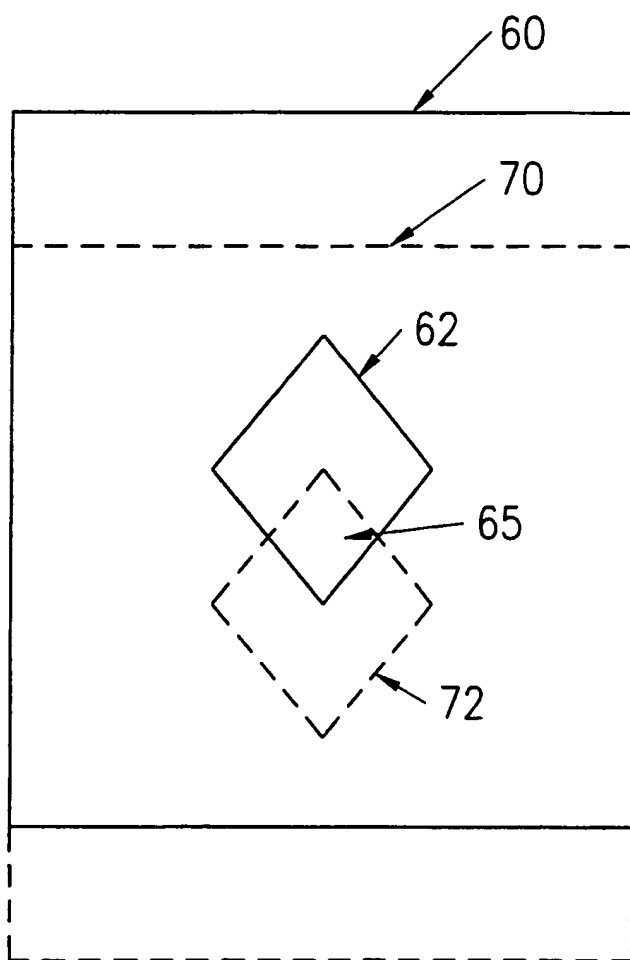
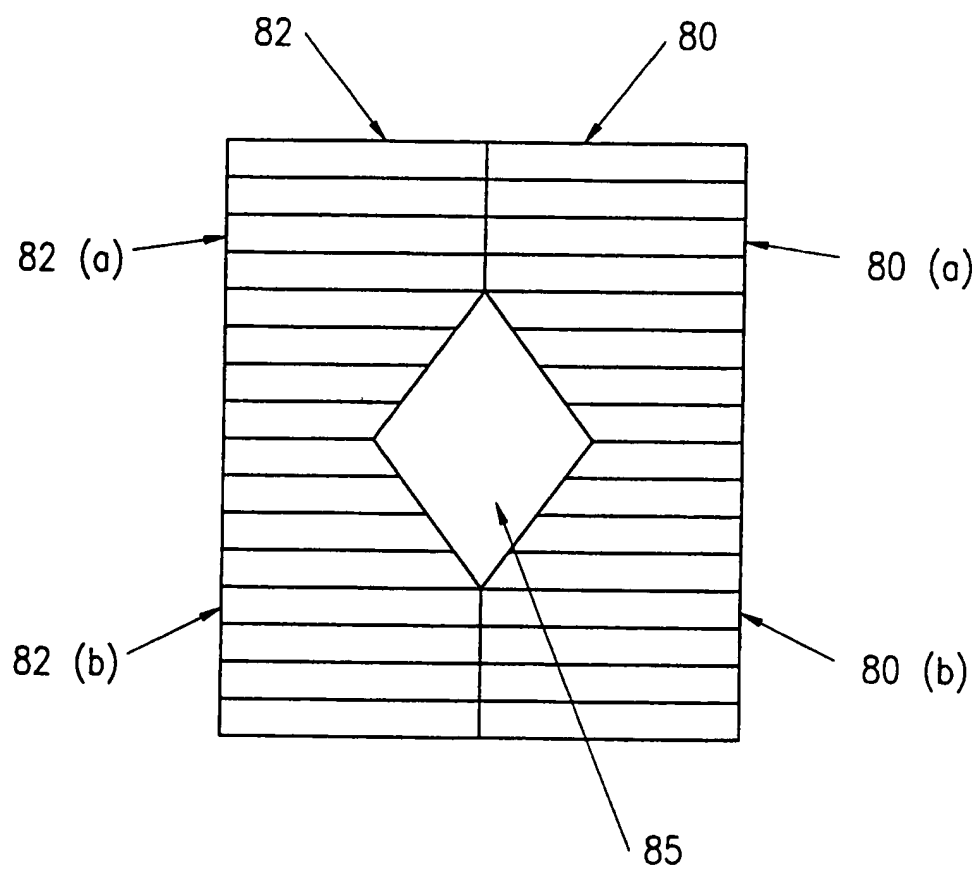


FIG. 3

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FIG. 4

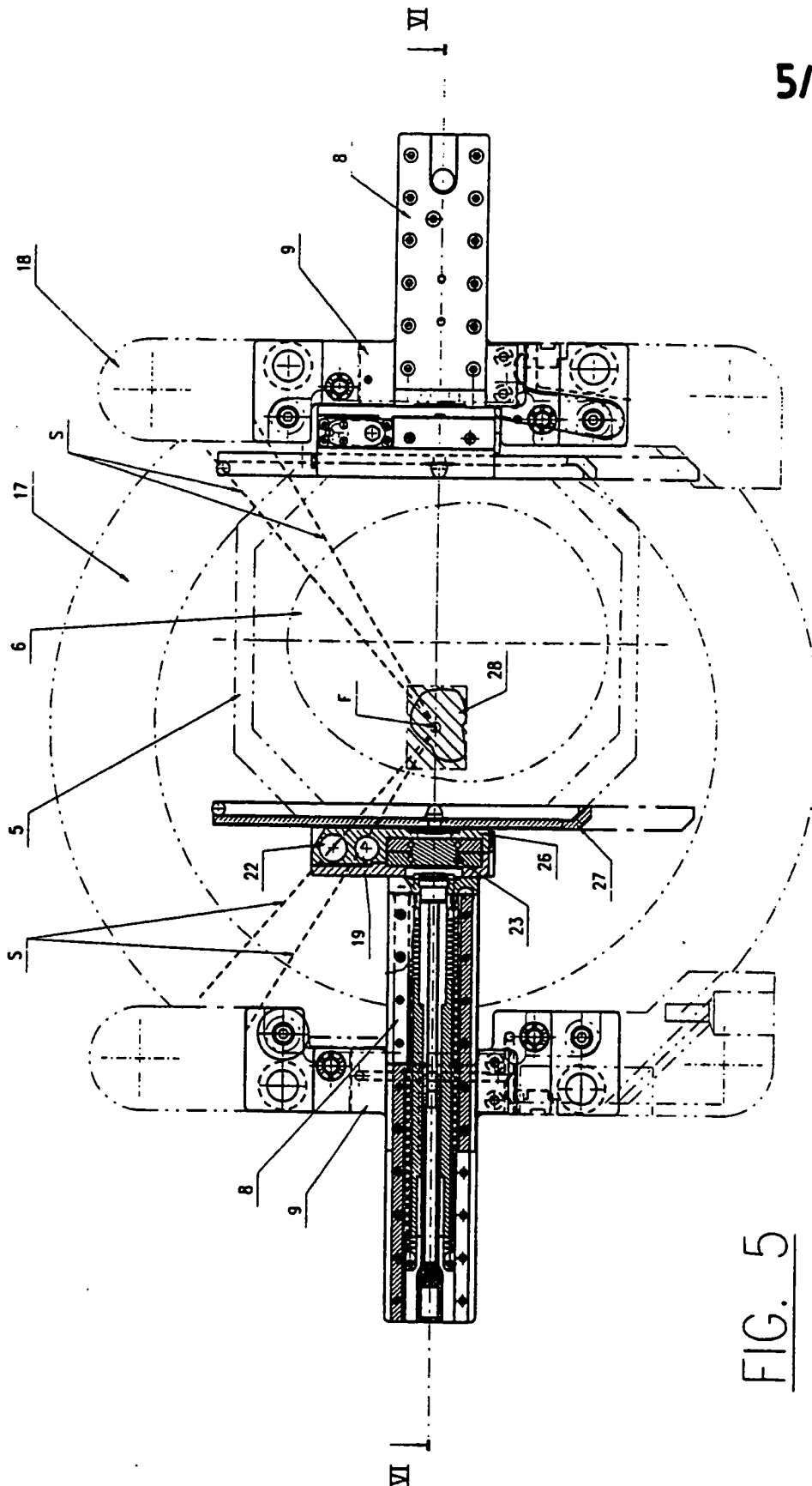
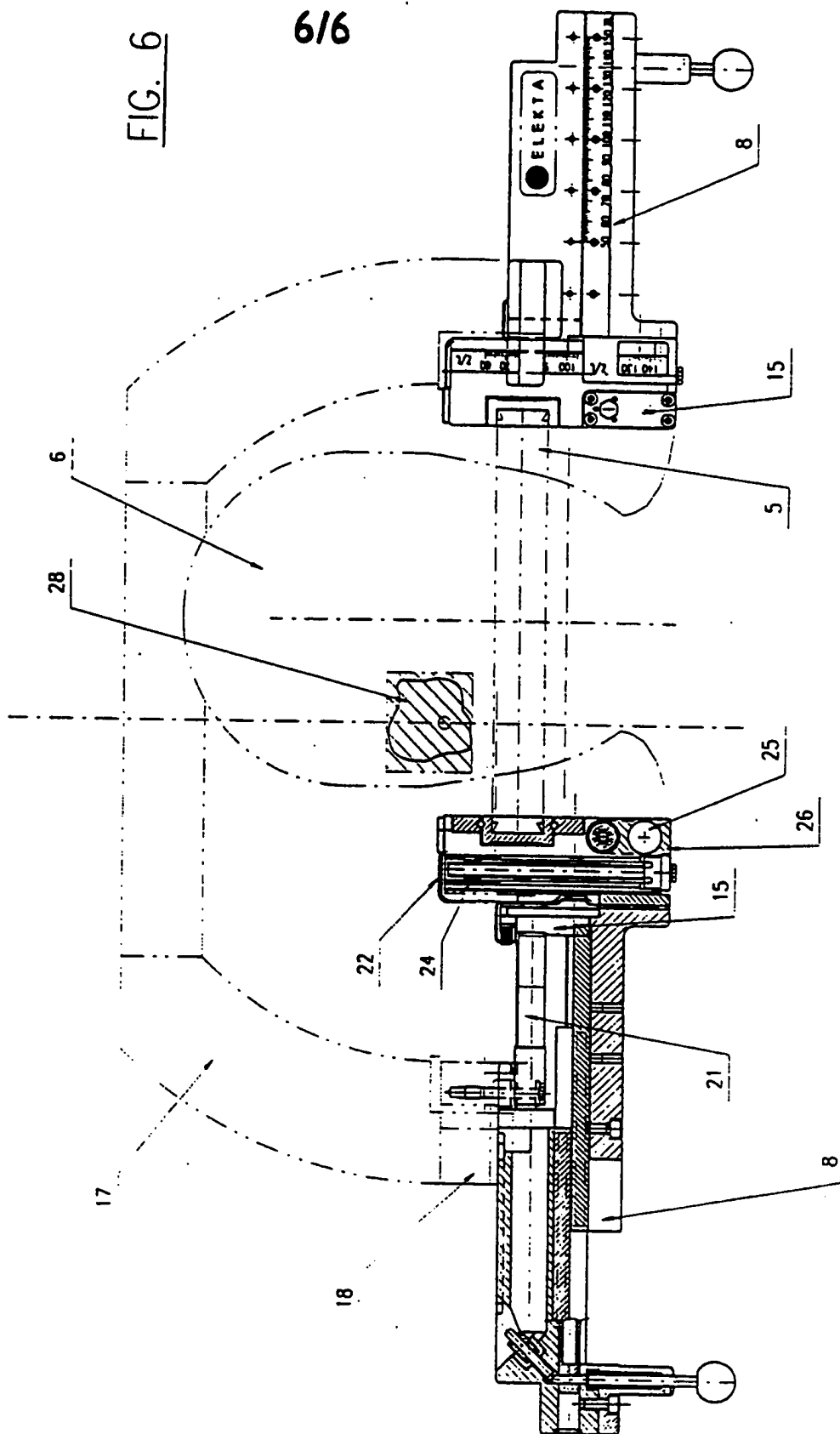


FIG. 6

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## INTERNATIONAL SEARCH REPORT

Intern. application No.

PCT/SE 95/00695

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>		
IPC6: A61N 5/10, A61B 6/08 According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols)		
IPC6: A61B, A61N, G06F		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
SE,DK,FI,NO classes as above		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0562585 A2 (IKEBE, JUN), 29 Sept 1993 (29.09.93), column 2, line 23 - line 47	1,2,5,8-10
Y	--	6,7
X	US 5107839 A (P.V. HOUDEK ET AL.), 28 April 1992 (28.04.92), column 2, line 61 - column 3, line 20; column 9, line 2 - line 21; column 9, line 39 - line 59	1,3,4,9-12
Y	--	6,7,13
X	EP 0480035 A1 (YOKOGAWA MEDICAL SYSTEMS, LTD), 15 April 1992 (15.04.92), column 2, line 39 - line 56; column 4, line 16 - line 21	1,3,4,9-12
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<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "B" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
18 Sept 1995		27-09-1995
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86		Authorized officer  Malin Keijser Telephone No. +46 8 782 25 00

## INTERNATIONAL SEARCH REPORT

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PCT/SE 95/00695

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	US 5278886 A (T. KOBIKI ET AL.), 11 January 1994 (11.01.94), abstract  --	13
P,X	US 5341292 A (R.G. ZAMENHOF), 23 August 1994 (23.08.94), abstract  -- -----	1,6,7



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28/08/95

International application No.

PCT/SE 95/00695

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US-A-	5278886	11/01/94	JP-A-	5188199	30/07/93
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US-A-	5341292	23/08/94	NONE		
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